GEOLOGY AND GEOTHERMAL POTENTIAL
OF THE ROOSEVELT HOT SPRINGS AREA,
BEAVER COUNTY, UTAH

by

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A thesis submitted to the faculty of the
University of Utah in partial fulfillment of the requirements
for the degree of

Master of Science

in

Geology

Department of Geology and Geophysics

University of Utah

Summer 1975

UNIVERSITY OF UTAH GRADUATE SCHOOL

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ACKNOWLEDGEMENTS

The writer wishes to express appreciation to the Utah Geological and Mineral Survey for financial support that made possible this study. Particular thanks go to Dr. William P. Hewitt, past Director of the Survey, for suggesting the project and for never-failing encouragement.

My advisor, Dr. Harry D. Goode, supplied helpful suggestions and critical review, which were much appreciated. Sincere thanks are also extended to Dr. James A. Whelan, who provided valuable discussion and suggestions.

James Lindsay kindly furnished color stereo aerial photographs, which proved to be extremely useful.

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ABSTRACT

The Roosevelt area contains Roosevelt Hot Springs, one of two Known Geothermal Resource Areas in Utah. The Roosevelt area is located on the western flank of the Mineral Range in Beaver County.

Precambrian(?) metamorphic rocks and Tertiary igneous rocks crop out in the eastern part of the Roosevelt area. Unconsolidated deposits of Tertiary and Quaternary age cover most of the Roosevelt area.

The Precambrian(?) metamorphic rocks, principally biotite gneiss, are present both as isolated outcrops and as blocks within the granite of the Mineral Range pluton. The pluton is primarily composed of coarse- to medium-grained granite. Radiometric age determinations show that parts of the pluton range in age from late Miocene to early Pliocene.

Silicic volcanic rocks crop out in Negro Mag Wash and in Wildhorse Canyon. In both areas, the volcanic rocks were extruded onto an eroded surface of the granite and are thought to be Pliocene in age.

No pre-Tertiary sedimentary rocks crop out within the Roosevelt area. Most of the area is covered by alluvial fan deposits. Most of the alluvium was derived from the granite, but some was derived from the silicic volcanic rocks. Some of the alluvium was worked into _V_-shaped embankments at different stages of Lake Bonneville.

North-trending faults are present within the foothills of the Mineral Range in the Roosevelt area. Another conspicuous north-trending fault, the Dome Fault, offsets Units A and C and also Pleistocene(?) hot-spring deposits. A well that yielded steam may have penetrated the Dome Fault. The west block of the Dome Fault is displaced upward relative to the east block; movement on the fault occurred during the Pleistocene. North- and northeast-trending faults that produced small displacements in the alluvial fan surface were mapped in the central and western parts of the Roosevelt area. An east-trending fault may be present beneath Negro Mag Wash.

Roosevelt Hot Springs are no longer flowing, but a patch of soil near the main orifice is 204°F. Other patches of warm ground and small deposits of siliceous sinter are present in Negro Mag Wash. Three rock units of silica-cemented alluvium, called Unit A, Unit B, and Unit C, and differentiated on the bases of lithology, outcrop pattern, and degree of sorting, were mapped in the Roosevelt area. Approximately 50,000 square feet of siliceous sinter is exposed at the south end of the Dome Fault. Several holes were drilled in and around this siliceous sinter deposit. One hole reached a depth of 275 feet, where steam blew the drilling equipment out of the hole; the temperature of the steam was 270°F.

The silica geothermometer and the sodium-potassium-calcium geothermometer were both applied to published analyses of Roosevelt Hot Springs water. The silica geothermometer indicated reservoir temperatures of 210° and 195°C; the Na-K-Ca geothermometer gave temperatures of 298° and 292°C.

The presence of relatively young intrusive and extrusive igneous rocks, the steam well, hot springs, and the favorable geochemical data all indicate that a hot subsurface igneous body exists in this area. Primary porosity in the granite and the metamorphic rocks is probably very low; secondary porosity along faults may be very important. There are not sufficient data to evaluate the hydrologic conditions that might prevail in a geothermal system in the Roosevelt area.

INTRODUCTION

Purpose and Scope of Report

In recent years, geothermal reservoirs have been recognized as valuable natural resources, and these systems are now the object of much exploration.

Roosevelt Hot Springs is one of two areas in Utah that were designated as Known Geothermal Resource Areas by personnel of the U. S. Geological Survey (Godwin and others, 1971). The other area was Crater Hot Springs, also known as Abraham Hot Springs, in Juab County. The area surrounding Roosevelt Hot Springs was considered to be a good prospect because the spring waters were reported to be very hot and to have a high silica content, and because relatively young igneous rocks crop out nearby (Jack Smedley, 1973, personal communication). The geologic framework of Roosevelt Hot Springs was not well known, however.

The purpose of the present investigation is to provide a geologic map of Roosevelt Hot Springs and adjacent areas, herein referred to as the Roosevelt area, and to use the geologic information to draw inferences about subsurface conditions and the likelihood of a geothermal reservoir in the Roosevelt area.

This report describes the rocks, old hot springs, opal deposits, and steam well of the Roosevelt area; and examines the volcanic history, alteration patterns, structure, and geomorphology of the area. A calculation of the subsurface temperatures indicated by the chemistry of the hot spring water is also included.

The data of this study were gained from mapping and petrologic examination of rock outcrops, inspection of aerial photographs, and a literature search. Some information on pre-existing drill holes is included in this report, but no drilling or geophysical surveys were undertaken for this study.

Location and Accessibility

A group of hot springs on the western flank of the Mineral Range was first described by Lee (1908), who mentioned two names for the group: Roosevelt Hot Springs and McKeans Hot Springs. The name Roosevelt Hot Springs was preferred by Mundorff (1970), and was followed by Godwin and others (1971) and Petersen (1973a). That name is also in current local usage.

In this report, the name "Roosevelt area" is used for the area lying between the Mineral Range on the east and the Escalante Valley (also known as the Milford Valley) on the west, and extending for a few miles north and south of the abandoned Roosevelt Hot Springs Resort. The northern border of the area approximately coincides with the northern edges of sections 35 and 36, T. 26 S., R. 10 W., and of sections 31, 32, 33, and 34, T. 26 S., R. 9 W. The western part of the area is bounded by the western edges of sections 15, 22, 27, and 34, T. 27 S., R. 10 W. The southern border of the area is the southern edge of T. 27 S.; and the eastern border is in sections 2, 11, 14, 23, 27, and 34, T. 27 S., R. 9 W. The total area is about 49 square miles.

The Roosevelt area is in Beaver County, Utah, about 160 air miles south-southwest of Salt Lake City. The town of Milford is three miles southwest of the Roosevelt area, and the town of Beaver is fourteen miles to the southeast, on the east side of the Mineral Range (see figure 1).

Utah State Highway 257 is about two miles from the Roosevelt area, paralleling the west side of the Mineral Range. Access into the Roosevelt area is provided by a graded gravel road that connects with Highway 257. Ungraded jeep trails extend into most parts of the Roosevelt area, and many are passable when dry to two-wheel-drive vehicles with high clearance.

The main line of the Union Pacific Railroad lies between the Roosevelt area and Highway 257.

Field and Laboratory Methods

Field work in the Roosevelt area was started in September, 1972, but most of the work was done during the summer of 1973.

Because topographic maps of the Roosevelt area were incomplete, U. S. Geological Survey aerial photographs at a scale of 1:40,000 were used as a base to plot the geology. Stereopairs of these photos were also used in locating the small-scale faults and disrupted drainage patterns that are discussed later in this report.

A plane table map (fig. 2) at the scale of 1 inch = 600 feet was made for one portion of the Roosevelt area. The map includes Roosevelt Hot Springs Resort on the north and the opal deposits on the south. This method of mapping was selected because the hot spring vents and other small features cannot be located with

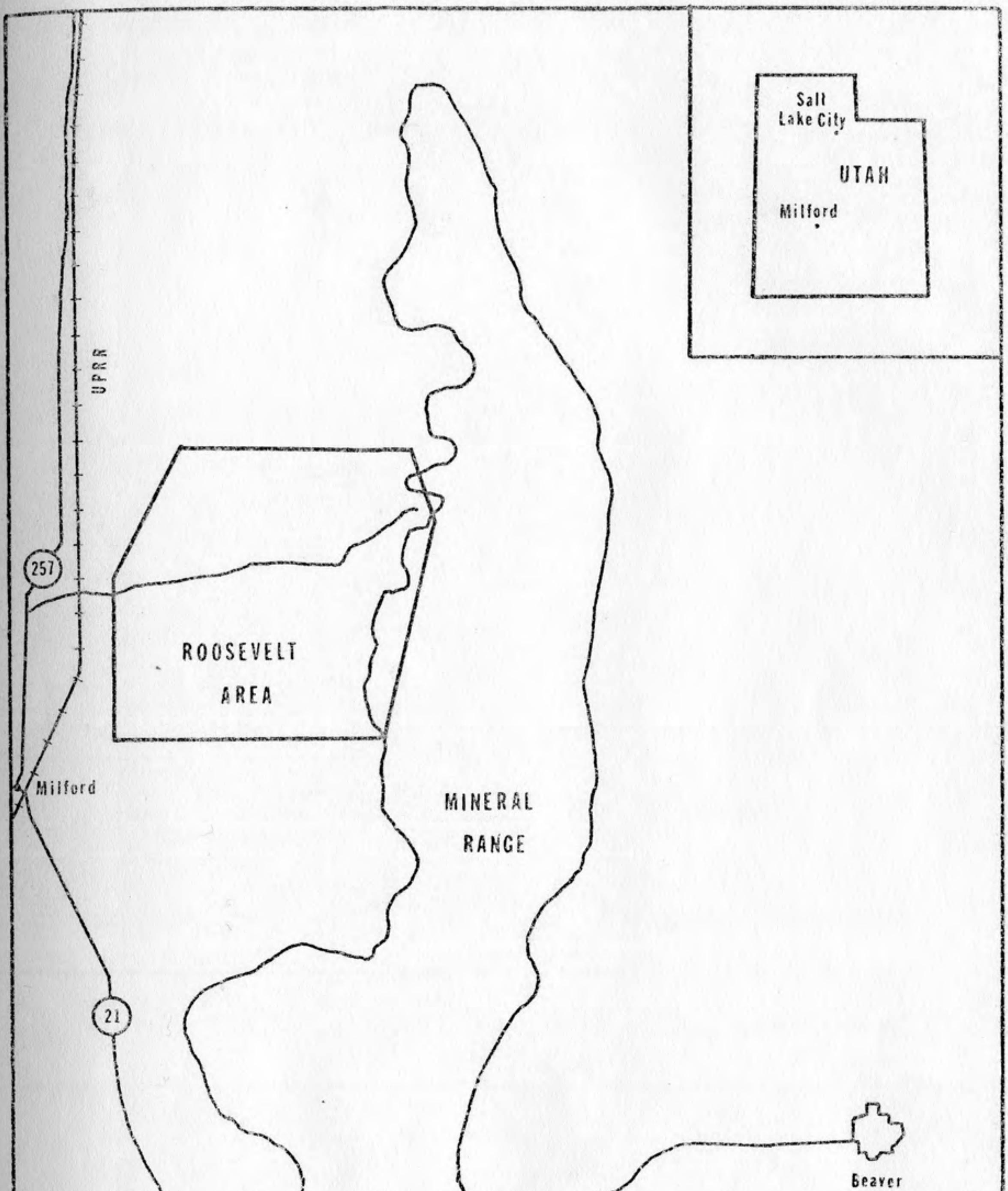

Figure 1.-- Map showing the location of the Roosevelt area.

sufficient accuracy on the aerial photographs, and because the surveyed map provided horizontal control for the photographs.

Colored stereo aerial photographs of the Roosevelt area were furnished by James Lindsay of Lindsay Earth Exploration and Research Company, and were used to add details to figure 2.

Topographic maps at the scale of 1:24,000 for the Roosevelt area became available during the summer of 1974. Parts of the Ranch Canyon, Minersville 2 NE, Black Rock 3 SW, and Black Rock 3 SE maps were used to construct a base map of the entire Roosevelt area ; and the outcrops, north-trending faults in the foothills of the Mineral Range, and the small-scale faults in the alluvium were plotted on it. This map is included as figure 3.

Geography

Topography and Drainage. The Roosevelt area lies between the Mineral Range and the Escalante Valley. Most of the area is underlain by an alluvial fan that formed as rock debris was shed from the Mineral Range. The elevation of the fan is about 5040 feet at the western margin of the Roosevelt area, and is about 6000 feet at the base of the Mineral Range foothills. The gradient of the alluvial fan is about 235 feet per mile in the eastern one-third of the area, but is only 140 feet per mile in the remainder of the area.

The general trend of the central portion of the Mineral Range is north. Long, rugged ridges project westward from the main body of the Mineral Range; the western extremities of several of these ridges are contained within the area of this report and were referred to above as foothills of the Mineral Range. One ridge attains an elevation of 7150 feet within the area of this report. The maximum elevation of the Mineral Range directly to the east of the Roosevelt area is 9095 feet at the crest of Bearskin Mountain.

Negro Mag Wash is the major drainage in the Roosevelt area. It has cut through the alluvial fan in a west-northwesterly direction, and in some places the stream bed is 100 feet below the adjacent alluvial fan surface. Elsewhere in the Roosevelt area, the drainage channels are shallow, and trend westward.

All drainage in the Roosevelt area is westward toward the Beaver River. There are no perennial streams or springs in the Roosevelt area; and all drinking water must be carried into the area.

Climate and Vegetation. The climate of the Roosevelt area is temperate and dry. Weather records at the nearby Milford Airport show that the mean annual temperature is 49.2 degrees Fahrenheit, and the mean annual precipitation is 8.57 inches (see Table 1).

Sage brush and short grasses cover most of the Roosevelt area. There are junipers in the northeastern part of the area, and a few pine trees on the foothills of the Mineral Range.

Land Utilization and Population. In recent years, the opal deposits in sec. 16, T. 27 S., R. 9 W., have been worked under a state minerals lease. Perlite has been mined in section 1 of the same township. Land use in the rest of the area is restricted to grazing for cattle and sheep during parts of the year.

The opal leaseholder camps near the opal workings during the summer months, and sheepherders, ranchers, hunters, and prospectors

Table 1.--Precipitation and average temperature of the Milford Valley, 1966-1972. Local Climatological Data: Milford, Utah: U. S. Department of Commerce, NOAA Environmental Data Service, 1972.

Total Precipitation

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1966	0.57	0.88	0.42	0.59	0.28	0.11	0.15	0.40	0.25	0.99	0.34	2.45	7.43
1967	1.07	0.20	1.10	0.41	0.55	2.43	1.42	0.32	2.60	0.22	0.52	0.83	11.67
1968	0.17	0.87	1.08	1.33	0.46	0.15	0.97	0.98	0.12	0.93	0.27	0.83	8.16
1969	1.63	1.27	1.17	1.76	0.27	1.22	1.36	0.64	0.44	0.90	0.63	0.34	11.63
1970	0.23	0.35	0.86	1.09	0.08	0.28	1.38	0.76	1.33	0.27	0.74	0.45	7.82
1971	0.25	1.30	0.31	0.91	1.06	0.15	0.48	1.59	0.49	2.47	0.20	1.33	10.54
1972	0.05	0.01	0.00	0.96	0.02	0.66	0.04	2.52	0.62	2.61	0.95	2.21	10.65
Mean of Record	0.62	0.78	0.98	0.84	0.66	0.43	0.73	0.74	0.57	0.82	0.63	0.77	8.57

Average Temperature

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1966	24.9	28.9	38.6	47.6	59.8	66.1	74.9	73.4	64.1	49.3	41.5	26.0	49.6
1967	21.1	33.6	42.5	42.8	54.4	62.1	75.3	75.7	64.2	52.3	41.8	19.6	48.8
1968	24.1	39.5	41.5	42.7	54.6	67.2	74.3	67.9	61.0	50.9	37.9	25.2	48.9
1969	33.0	32.4	35.1	48.2	61.2	63.1	74.9	77.1	66.7	44.1	36.0	31.8	50.3
1970	31.0	37.8	37.0	41.7	57.1	66.1	75.1	75.9	59.2	46.0	40.0	30.1	49.7
1971	29.8	30.4	38.4	46.7	52.9	66.1	75.7	74.2	58.7	45.0	34.8	25.1	48.2
1972	29.1	35.7	44.3	47.6	56.7	68.2	75.7	70.5	61.0	49.6	34.9	15.8	49.1
Mean of Record	25.6	32.1	39.4	47.7	56.6	65.6	74.4	72.2	62.3	50.1	37.1	27.7	49.2

occasionally visit the Roosevelt area, but there are no permanent residents.

Previous Investigations

The geology of the Mineral Range was first discussed by W. T. Lee (1908). His paper also includes a description of Roosevelt Hot Springs and an analysis of the spring water.

Butler and others (1920) described mining districts in the Mineral Range. Crawford and Buranek (1943, 1945) studied tungsten deposits of the southern and eastern sides of the range.

Two theses dealing with the Mineral Range were completed at the University of Utah in 1957. Liese (1957) mapped the northern Mineral Range, including the northeastern part of the Roosevelt area; and Earll (1957) mapped the rest of the Mineral Range, which he called the central Mineral Range. Earll's map included the southeastern part of the Roosevelt area. Both of these investigations dealt with the general geology of the Mineral Range, and devoted very little attention to the Roosevelt area. In the course of the present study, the geologic maps of Liese and Earll were checked in those portions of the Mineral Range that are included in the Roosevelt area. In general, the locations of the granite and the metamorphic rocks are correctly mapped. However, neither Liese nor Earll correctly identified the hot spring deposits of the Roosevelt area. Neither author mentions the fault that offsets the hot spring deposits, or the smaller faults in the alluvial fan. One object of the present study was to amplify the previous geologic mapping of the Roosevelt area.

Condie (1960) studied the Mineral Range pluton in order to determine its origin, and concluded that (1960, p. 79) the Mineral Range pluton and its apophyses were probably formed by the process of granitization.

GENERAL GEOLOGY

The bedrock of the eastern part of the Roosevelt area consists of metamorphic biotite gneiss, schist, and phyllite of Precambrian(?) age, intrusive granite and lamprophyric dikes of late Tertiary age, and two extrusive glassy silicic flows of probable Pliocene-Pleistocene age. Bedrock is not exposed in the central and western parts of the area. Unconsolidated deposits, principally alluvium of Tertiary and Quaternary age, cover most of the Roosevelt area.

In addition, there are exposures of opal and siliceous sinter that were deposited by hot springs, and three rock units that consist of silica-cemented alluvium. These deposits are discussed in the section on hot springs, hot-spring deposits, and wells.

The Mineral Range is a fault-block mountain range. In the Roosevelt area, north- and northeast-trending faults are present within the alluvial fan. Hot-spring activity occurred along and near one of these faults, the Dome Fault. An east-trending fault may be present beneath Negro Mag Wash.

Stratigraphy

Metamorphic Rocks

Distribution

A zone of Precambrian(?) metamorphic rocks was mapped in the foothills of the Mineral Range by Liese (1957) and Earll (1957).

Additional small outcrops of metamorphic rocks, which are undoubtedly part of the same unit, were mapped in sections 9 and 3, T. 27 S., R. 9 W., and in section 34, T. 26 S., R. 9 W. during the present investigation (see figure 3 for locations).

Condie (1960, p. 26) proposed that the metamorphic rocks be named the Wildhorse Canyon Series.

Lithology

Earll (1957, p. 9) states that metamorphic rocks occur in a zone from Negro Mag Wash (called Hot Springs Canyon by him) south to Ranch Canyon. Biotite gneiss makes up most of the exposed metamorphic rocks, but schists and phyllites are also found in the area. The composition of the gneiss is: biotite, 50 percent; quartz, 40 percent; orthoclase, 8 percent; magnetite, 2 percent; and minor muscovite and zircon (Earll, 1957, p. 9).

Liese (1957) mapped a zone of basic rocks north of Negro Mag Wash. He suggests (1957, p. 65) that the zone may be composed of metamorphic rocks that were partially assimilated by the granitic magma and that may have been partially granitized in place. The zone is mainly composed of dark, ferromagnesium-rich constituents, and there is a distinct but narrow (up to 50 feet) transitional contact with the granite (Liese, 1957, p. 61). Rocks of the basic zone do not show metamorphic structures.

Variations of composition within the basic zone were described by Liese (1957, p. 64-65) in terms of the equivalent igneous rocks. Liese gives petrographic descriptions of samples having dioritic, granodioritic, and quartz monzonitic composition.

The outcrops of Precambrian(?) rocks in sections 3 and 9 show metamorphic structures, but the structures are not as well developed as in the biotite gneiss zone mapped by Earll. Biotite gneiss is the predominant rock type in these outcrops. Fresh rock has dark brown and white bands, which are about one-quarter inch wide; weathered rock is dark gray or brown. Soil produced from the metamorphic rock is reddish-brown.

In hand specimen, the gneiss is seen to be composed almost entirely of biotite and quartz. Limited examination of mineral fragments in oil immersion shows that the biotite grains are relatively unaltered.

Contact Relations

Both Liese and Earll emphasize that the metamorphic rocks in the Mineral Range are in gradational contact with the granite. Earll (1957, p. 9) states that the contact zone, which ranges up to one-quarter mile in width, contains numerous blocks of gneiss that have been separated from the main mass by the intruding granite; and smaller inclusions of the metamorphic rock in the granite are common. Both Liese and Earll note that the granite becomes richer in biotite near the contact zone, and both authors suggest that the granite assimilated some of the metamorphic rocks.

The western contacts of the metamorphic rocks of the foothills are covered by alluvium.

Contact relations of the metamorphic rocks in sections 9, 3, and 34 with other bedrock in the area are hidden by alluvium.

Age

The gneisses and schists of the Mineral Range were assigned a Precambrian(?) age by Earll (1957). This assignment is principally based on the metamorphic grade of the rocks.

Igneous Rocks

Intrusive igneous rocks of the Roosevelt area include granite and a few lamprophyric dikes. Extrusive igneous rocks include two silicic flow units.

Intrusive Rocks

Granite

Only a small part of the Mineral Range pluton is included within the area of this report. To the east, north, and south of the Roosevelt area, about 54 square miles of granite crops out within the main body of the Mineral Range (Earll, 1957, p. 47). Most inselberge on the flanks of the Mineral Range are composed of granite, and if the alluvium were not present, the total surface area of the pluton might be as great as 100 square miles (Earll, 1957, p. 47).

Foothills of the Mineral Range within the Roosevelt area are mostly granite, and this rock type makes up more than half of the consolidated rocks cropping out within the Roosevelt area.

Lithology. Liese (1957) and Earll (1957) both describe the central portion of the Mineral Range pluton as a coarse-grained, equigranular white granite. Earll (1957, p. 48) reports that quartz varies from 10 to 25 percent; orthoclase, 70 to 80 percent;

plagioclase (variety oligoclase), 3 to 5 percent; biotite, less than one percent. According to the new international classification of plutonic rocks (Streckeisen, 1973, p. 26), rocks with this range of composition plot in the field of alkalai-feldspar granite or the field of alkalai-feldspar quartz syenite. The microscopic texture of the rocks is hypautomorphic granular. Liese (1957, fig. 4, in pocket) gives a sketch of a typical thin section of the granite.

The granite of the Roosevelt area generally contains more mafic minerals than the granite in the central portion of the pluton. For example, limited examination using oil immersions shows that a hand specimen of granite from the northeast quarter of section 3 contains about 45 percent potassium feldspar, 35 percent quartz, 15 percent chlorite after biotite, and 5 percent accessories, including opaque grains, apatite, and sphene. The rock is medium-grained, has a salt-and-pepper coloration, and weathers to medium brown. This outcrop has a rounded, blocky appearance that is typical of most of the granite in the Roosevelt area.

However, some granites in the Roosevelt area show another style of outcrop: they appear to be dikes that have intruded into granite or metamorphic rocks. An excellent example of a granite dike occurs in the southeast quarter of section 3. The granite is a twenty-five foot thick tabular body that strikes N7^{o}E and dips 20^{o}E. Fresh rock is light gray and medium-grained; weathered rock is medium brown or dark brown. A hand specimen contains about 40 percent potassium feldspar, 35 percent quartz, 20 percent chlorite after biotite, and 5 percent accessories, including magnetite, sphene, and apatite.

Age. Two radiometric age determinations have been made on the Mineral Range pluton. Armstrong (1970, p. 216-217) dated biotite from granite on the west side of the pluton as 9.2 ± 0.3 million years old. Park (1968, p. 74) obtained 15.5 ± 1.5 million years for fine-grained granitic dike material from the southeast side of the range. If the age determinations of Park and Armstrong are correct, parts of the pluton range in age from late Miocene to early Pliocene.

Field relations show that the pluton is younger than Jurassic but older than the silicic volcanic rocks; because the youngest rocks intruded by the pluton are Jurassic limestones of the Carmel formation, and the silicic volcanic rocks overlie the pluton.

Extrusive Rocks

Silicic volcanic rocks cap the Mineral Range to the east of the Roosevelt area, and some of the flows extend into the area of this report. The volcanic rocks were discussed very briefly by Liese (1957) and Earll (1957). Their work was mentioned by Condie (1960, p. 24-25), who proposed the name "Ranch Canyon Volcanics" for the group.

The present investigation treats the previously mapped volcanic rocks very briefly because it was felt that a detailed study of the small exposures that are included in the Roosevelt area would not be meaningful. A careful study of the petrology and field relations of the Ranch Canyon Volcanics would probably give good information on the history of the Mineral Range; but insufficient time and the lack of suitable base maps precluded such a study during the present investigation.

Silicic Flow Rocks

Two silicic flow units are included in the area of this report; one in Negro Mag Wash and one in Wildhorse Canyon.

Negro Mag Wash Unit. This unit has a total thickness of about 200 feet. Two layers of dense, welded black glass are exposed on the north side of the unit, and may indicate that the unit is composed of two flows. Rock from the top of the unit is light gray to white in color and is very porous; it was probably emplaced as a pumice flow. This rock has been mined as perlite.

The flows may be as old as Late Pliocene because the unit shows some dissection. It is not known whether this unit is contemporaneous with the Wildhorse Canyon Unit.

Wildhorse Canyon Unit. The Wildhorse Canyon Unit is about 400 feet thick at its lower end. It is probably composed of two flows, with the base of each flow being a layer of obsidian, and the upper part of each flow being a tan to gray glassy rock.

The age of this unit is thought to be Pliocene because one stream channel is cut 50 feet down into the flow unit, and an integrated drainage has developed on the south side of the unit, and also because a reddish-brown soil has developed on the obsidian at the front of the flow.

The remnants of an ash deposit are found in the fault(?) valley on the north side of the flow in section 23. The deposit is about forty feet thick where it has been exposed in a prospect pit. The ash is white and is exceedingly fine grained (silt sized); the only larger particles contained in the deposit are a few pumice pebbles. No fragments of granite or metamorphic rock were observed in the deposit. The ash shows stratification, with white layers one inch to two feet thick being separated by very thin layers of light gray ash. No channel-filling, cross bedding, ripple marks, or other indicia of deposition by moving water were observed.

From this evidence, it is suggested that the fault(?) valley had been dammed by extrusion of the silicic flows, and that the ash fell from the air into a small lake.

Unconsolidated Deposits

Most of the Roosevelt area is covered with alluvium that was eroded from the granite and silicic flows. In the western part of the area are three large V-shaped embankments that were probably deposited by waves and currents in ancient Lake Bonneville.

Alluvium

Thick alluvial fan deposits blanket nearly all the Roosevelt area. Most of the alluvium consists of fragments derived from the granite. The fragments are usually less than one-quarter inch long and are composed principally of quartz and potassium feldspar, with accessory magnetite. Cobbles of volcanic rocks in the alluvial fan are as large as four inches in the longest dimension, and are found both north and south of Negro Mag Wash. Material derived from the volcanic rocks makes up less than one-quarter of the total volume of the alluvium.

About forty feet of alluvium overlies the metamorphic rocks in Negro Mag Wash, and about the same thickness of alluvium is exposed in the walls of Ranch Canyon. No pediment surface is visible.

Age of the Alluvial Fan. The alluvial deposits have been called Quaternary by Liese (1957) and Earll (1957). However, one part of the fan may be older.

A road cut in the southeast quarter of section 9 shows a number of very deeply weathered boulders, which are composed of metamorphic and granitic rocks. The boulders are as large as three feet in diameter and most are rounded. The road cut is on the margin of a metamorphic outcrop, and the boulders probably were not transported far from their place of origin.

The boulders exposed in the road cut are easily friable. Two explanations can be proposed to account for this fact: (1) the boulders have been exposed to percolating cool ground water that caused weathering *in situ*, or (2) hot waters rising along the fault attacked the rocks and caused deep corrosion of the boulders. Little chlorite or epidote was observed in the deeply weathered boulders, so the first explanation is considered more likely; and the deeply weathered boulders may be older than Quaternary.

V-embankments

The western part of the Roosevelt area contains three large triangular deposits, which are *V*-embankments of the type first described by G. K. Gilbert (1890, p. 57-59). The locations of these deposits are shown on figure 3. The embankments are composed of gravel, pebbles, and cobbles that were derived from the granite and the silicic volcanic rocks.

The largest of the three V-embankments of the Roosevelt area is in section 27, T. 27 S., R. 10 W. The length of the "baseline", measured between the places where the sides of the V-embankment adjoin the alluvial fan, is about 3600 feet; and the distance from the point of the V-embankment to the "baseline" is about 2000 feet. The point is 50 feet higher than the surrounding valley floor. The other two V-embankments are slightly smaller.

Two more V-embankments are located just north of the edge of the Roosevelt area. All of the V-embankments are well preserved.

Gilbert (1890, p. 58) suggests that the V-embankments were formed in the following manner: Currents and waves formed triangular terraces. Then the lake increased in size, so that the triangular terraces were immersed beneath a few feet of water; then additions were made to the terraces by the building of linear embankments at their outer margins.

The V-embankments of the Roosevelt area and those just outside the Roosevelt area were formed at different stages of Lake Bonneville, because they are at different elevations. One of the V-embankments outside the Roosevelt area overlaps another V-embankment. The aerial photographs do not show any evidence that the small-scale faults (discussed below) have offset the V-embankments or caused the differences in elevation among them.

Structure

Faults

Basin and Range Faults

The Mineral Range is classified as a fault-block mountain range, similar to many ranges in the Basin and Range province. It is flanked on the east by Beaver Valley, and on the west by the Escalante Valley, also known as the Milford Valley. According to Cook and Mudgett (1966, p. 62), the eastern side of the Milford Valley graben near the Mineral Range contains a maximum of about 5,500 feet of valley fill.

A Basin and Range fault or fault zone may extend in a north-south direction through the center of the Roosevelt area. Small scale north- and northeast-trending offsets in the alluvium, which are discussed below, may be the surface expression of such a Basin and Range fault.

North-south Faults

A north-trending fault is shown on figure 3 in sections 11, 14, and 23, T. 27 S., R. 9 W. The fault is inferred from an alignment of valleys that cross or nearly cross the foothills of the Mineral Range. The valleys are nearly equal in width and are perpendicular to the trend of the ridges. These topographic features are shown on the Minersville 2 NE Quadrangle topographic map (contour interval = 40 feet), but are more easily seen on vertical aerial photographs of the area.

The inferred fault occurs at or near the contact between the

Precambrian(?) metamorphic rocks and the Tertiary granite. The metamorphic rocks occur on the west side of the fault. The direction of movement on the fault is not known.

Faulting and development of the valleys occurred prior to deposition of a silicic volcanic flow in Wildhorse Canyon, because the flow extends laterally into the valleys on both sides. There is no evidence of movement on the fault subsequent to the deposition of the flow rocks. The time of movement on the fault is thought to be middle Pliocene.

Another north-trending fault, which is also inferred from topography, is shown in the southwest quarter of section 15, T. 27 S., R. 9 W. Precambrian(?) metamorphic rocks are exposed on both sides of the fault; and the direction of movement on the fault is not known.

Dome Fault. The Dome Fault, the most conspicuous fault in the Roosevelt area, extends in a north-northeasterly direction through sections 16, 9, and 4, T. 27 S., R. 9 W. Near Negro Mag Wash, the fault curves, and extends through sections 3 and 34 in a northerly direction (see figure 3).

The "Dome Fault" is so named because its maximum offset is in gently domed siliceous hot spring deposits in section 16. Here, the vertical displacement is at least twenty feet, with the west block up relative to the east block. Vertical displacement at the north end of the fault is probably about fifteen feet; but displacements in section 9 may have been smaller.

A well in section 16 (described on p. 38) hit steam, reportedly at 270 feet. If the zone containing much steam is the fault, then the fault plane dips 45° or more to the east. The strike of the fault in sections 16, 9, and 4 is inferred to be N 18°E. The actual fault plane is not seen at the surface.

Abundant cobbles of obsidian and perlite are at the surface of the alluvial fan on the west side of the fault in the northeast quarter of section 9. These cobbles were derived from the silicic flow in section 2, and show that movement on the fault postdates extrusion of that flow.

Inspection of aerial photographs shows that the fault has "disrupted" drainage on the alluvial fan, because a "beheaded" drainage can be discerned in the southern part of section 9; this feature is shown on figure 2. However, sufficient time has elapsed since faulting to allow erosion of a gully through the part of the scarp that had the greatest amount of vertical displacement. Because the fault scarp shows through-going drainages, most of the movement on the Dome Fault probably occurred no later than Pleistocene. The fault is therefore younger than the north-trending faults within the foothills of the Mineral Range.

Small Faults in the Alluvial Fan

A number of small-scale faults in the area between the Dome Fault and the western edge of the Roosevelt area (see figure 3) were mapped on aerial photographs. These faults are very difficult to locate on the ground because no consolidated rocks are exposed at the surface. Movement along the faults has produced ridges in the alluvium that trend north and northeast, perpendicular to the trend of the drainage. The ridges are easily seen on aerial photographs, and they can be seen from the foothills of the Mineral Range at sunrise and sunset, when the east-facing slopes of the ridges are illuminated differently from the alluvial fan surface.

Movement on the faults has formed a number of grabens and horsts, and these features show different erosional patterns. On aerial photographs, the grabens tend to be uniform in color, in contrast to the remainder of the fan. For example, the graben in the western half of section 29, T. 27 S., R. 9 W. is nearly uniform in color across its whole width of about one-half mile. An area of similar size on the unfaulted portion of the alluvial fan shows many color changes because of the channels. Differences in color on the aerial photographs are caused by changes in vegetation and slope angle. The horst blocks show deeper channels than the unfaulted portions of the fan.

The small-scale faults are probably younger than the Dome Fault. The main reason for supposing this is that at the surface, only unconsolidated alluvium is offset, and the evidence of faulting is probably erased by erosion within a geologically short time. Indeed, some of the traces of the small-scale faults are very faint, and are plotted as queried faults on figure 3. Perhaps these faults are older than the more conspicuous faults. By this reasoning, movement on the small faults is probably Pleistocene, and might even extend into the Holocene.

East-west Trending Fault(?)

A queried east-west trending fault is shown in Negro Mag Wash on figures 2 and 3. The principal evidence for the existence of this fault lies outside the Roosevelt area, and consists of an east-west trending ridge at the crest of the Mineral Range in sections 5 and 6, T. 27 S., R. 8 W. The ridge separates two relatively flat areas of bedrock granite at elevations of approximately 7200 feet and 7460 feet.

If this fault extends into the Roosevelt area, it is covered by alluvium. Movement on the fault probably predates both the silicic flow in Negro Mag Wash and the Dome Fault.

Geomorphology

The geomorphology of the Dome Fault scarp has been mentioned in a previous section.

However, several points should be made about the deepest drainage of the Roosevelt area, Negro Mag Wash. The wash is an underfit stream, which may indicate that the major episode of channel-cutting occurred during the pluvial periods of the Pleistocene. Also, cobbles of obsidian and perlite from the silicic flow south of the wash, in sections 1 and 2, are abundant on the alluvial fan north of the wash. This shows that Negro Mag Wash definitely postdates the silicic flow.

Summary of Geologic History

The rock units exposed in the Roosevelt area include only a few of the rock units exposed in the rest of the Mineral Range. Consequently, the geologic record of the Roosevelt area is fragmentary, and the record of nearby areas must be used as a guide.

The oldest rocks of the Roosevelt area are metamorphic rocks, including biotite gneiss, schist, and phyllite. It is postulated that both the accumulation of the original sedimentary rocks and the metamorphism took place during the Precambrian era.

No pre-Tertiary sedimentary rocks crop out within the Roosevelt area, although lower Paleozoic sedimentary rocks are exposed on the north end of the Mineral Range, and middle Paleozoic through Mesozoic sedimentary rocks occur on the southern end of the range. The central portion of the Mineral Range is composed of plutonic rocks, and has undoubtedly experienced the greatest amount of uplift and consequent erosion; and the pre-Tertiary sedimentary rocks that probably were present have been removed.

The Mineral Range pluton was emplaced during late Miocene or early Pliocene time. It was then uplifted and eroded. The postulated east-west fault and the north-south trending faults within the Mineral Range may have formed during the time of uplift. The larger north-trending fault was formed between early Pliocene and late Pliocene time, because the Wildhorse Canyon volcanic unit occupies a valley that was eroded along the fault.

The Ranch Canyon Volcanics were extruded onto an erosional surface of the granite. The silicic flows in Negro Mag Wash and Wildhorse Canyon were extruded during late Pliocene time.

The alluvial fan deposits of the Roosevelt area formed during late Tertiary and Quaternary time. During the Pleistocene, hot springs flowed in the Roosevelt area, and Units A, B, and C were formed of alluvium by the cementing action of the hot water. Some of the hot spring activity preceded the consolidation of Unit A, because that unit contains fragments of siliceous hot-spring material. Unit A is also overlain by extensive hot-spring deposits. The relative ages of Units A, B, and C are not known because most outcrops are widely separated by alluvium, and no bedrock contacts are exposed.

Movement along the Dome Fault and the small-scale faults in the alluvium occurred during the Pleistocene and perhaps also during the Holocene. Unit C, Unit A, and also overlying hot-spring deposits are offset by the Dome Fault. Other Pleistocene events in the Roosevelt area included the formation of the Lake Bonneville embankments and the cutting of Negro Mag Wash.

Other small siliceous deposits at the north end of the Dome Fault were produced by hot springs that flowed during historic times. It is not known whether hot springs flowed in the Roosevelt area between the time of formation of the Pleistocene hot-spring deposits and the formation of the recent hot-spring deposits.

DESCRIPTION OF HOT SPRINGS, HOT SPRING DEPOSITS,

AND WELLS OF THE ROOSEVELT AREA

The group of springs known as Roosevelt Hot Springs formerly issued from metamorphic rocks and alluvium on the western flank of the Mineral Range. Published reports do not record the number of springs in the group.

One spring was described by Lee in 1908 (p. 20), who said that it flowed at a rate of 10 gpm, and that the temperature was at least 190°F. Mundorff states (1970, p. 42) that the main spring was dry in 1966, and did not appear to have discharged for several years. The springs have not been observed to discharge during the course (1972-1973) of the present study.

The hot-spring deposits consist of three rock units that were formed from alluvium as a result of the cementing action of hot water, and also siliceous deposits that were formed by precipitation from hot-spring waters. The largest siliceous hot-spring deposits in the Roosevelt area are the Pleistocene(?) deposits at the south end of the Dome Fault; but smaller, relatively recent siliceous deposits are present in Negro Mag Wash.

In numerous places, the unconsolidated alluvium has been stained red, and the stained patches are interpreted to have once been hot springs or seeps. Although no water is presently being discharged to the surface at any of these places, hot ground in the bottom of trenches and auger holes shows that some hot water is still present in the subsurface. All of these features are discussed below, and all are shown on figure 2.

There is no record of any water wells in the Roosevelt area. However, several holes were drilled in the hot-spring deposits in section 16, and one is reported to have discharged steam.

Rocks Composed of Silica-Cemented Alluvium

Three rock units of silica-cemented alluvium that had not been previously reported were found in the Roosevelt area during the present investigation. All outcrops of the new units are near the Dome Fault.

The rock units are called Unit A, Unit B, and Unit C, and are divided into these units on the bases of lithology, outcrop pattern, and degree of sorting exhibited within the rocks. The area of outcrop of each unit is small, as can be seen from figure 2. Because most outcrops are widely separated by alluvium and because no bedrock contacts are exposed, the stratigraphic relationships among the units are not known.

Unit A

Distribution. Unit A is exposed in scattered outcrops in the Roosevelt area. One outcrop is at the north end of the Dome Fault, and the others are two miles south, at the extreme south end of the Dome Fault.

Table 2.--Composition of samples R-128 and R-17, Unit A.

	R-128		R-17	
Composite rock fragments	33%	51%	32%	51%
Fragmental quartz	4%		9%	
Fragmental potassium feldspar	12%		7%	
Fragmental plagioclase	2%		3%	
Biotite	6%		<1%	
Amphibole	not found		<1%	
Opaques	3%		3%	
Matrix	14%		21%	
Unfilled voids	7%		3%	
Opal	15%		14%	
Secondary Quartz	3%		3%	
Chlorite	1%		2%	
Epidote	not found		2%	
	100%		100%	
Number of points counted	318		315	

Lithology. The rock consists of rock fragments in a tan to brown glassy matrix. The fragments are granite or siliceous, banded hot-spring material. The matrix is porous and has small (less than 0.5 mm) flakes of biotite. Some rocks have opal-filled veins that are as wide as three-quarters of an inch.

Outcrops are massive and do not show any stratification or sorting of the rock fragments. The northern outcrop is jointed, forming horizontal slabs that are about eighteen inches thick. The rock weathers to medium brown or light brown.

Samples from the northern outcrop and from one southern outcrop were examined petrographically (sample locations are shown on figure 2). Composition of the rocks, as determined by point counts, is shown in Table 2.

Most of the rock fragments are composed of quartz, potassium feldspar, and opaque minerals; however, some are composed of only one of those minerals. Potassium feldspar fragments show both graphic and perthitic intergrowths. Many rock fragments touch one another, but some appear to be entirely surrounded by the matrix. The rock fragments are subrounded to angular and are as large as 20 mm in the longest dimension; the average length is about five mm. Most grains are half as wide as they are long.

Individual grains of biotite and of a green amphibole (possibly actinolite) are present in the matrix, but were not observed in any composite rock fragments. The biotite grains average one mm in length, are relatively unaltered, and are generally not bent. The amphibole grains average one mm in length and are subhedral.

The matrix consists of minute (less than 0.1 mm) mineral fragments and brown glass. The glass does not show any shards or other evidence that the texture originally was fragmental. Very little devitrification of the glass has taken place.

The rocks are quite porous. Irregularly shaped voids, averaging 0.5 mm in width, make up as much as seven per cent of the rock (see Table 2). None of the voids cut rock fragments. Thin opal rinds line most of the voids, and completely fill some. Epidote is associated with the opal. A few voids have been filled by quartz.

Mineral identifications by X-ray diffraction were made on a sample of the whole rock and on a light-mineral fraction of one sample of Unit A. Neither analysis showed any clay to be present in the sample.

<u>Origin of Unit A</u>. The data developed during the present investigation did not clearly show the mode of formation of these rocks. However, later research by W. T. Parry (1975, personal communication)

strongly suggests that Unit A consists of hydrothermally altered and cemented alluvium.

Because of the similarity of lithology between widely separated outcrops and because silicic volcanism occurs nearby, the writer has in the past suggested that Unit A might be a lithic tuff. The fact that no clay was found either optically or by X-ray diffraction in the samples studied by the writer seemed to support this interpretation. However, later work by Dr. Parry has shown that clay is present in the matrix of Unit A. Additionally, if Unit A were a lithic tuff, then vestiges of glass fragments should be visible in the matrix, but none have been found.

Age. Unit A contains fragments of siliceous hot-spring material, so the unit post-dates the first hot springs in the area. The unit is overlain by a large deposit of siliceous sinter, and is offset by the Dome Fault, so Unit A may be early or middle Pleistocene in age.

Unit B

Distribution. Unit B was found only in the southern part of section 9.

Lithology. Unit B forms a linear outcrop that resembles a dike. The outcrop is 275 feet long and averages two feet wide; it strikes N 9^{o}W, and has joints that dip 70^{o} to the west. In places, the rock is covered by a thin layer of alluvium.

The rock consists of rock fragments in a pale green to white glassy matrix. Outcrops are massive and do not show any stratification or sorting of the rock fragments. The rock weathers to white

Table 3.--Composition of samples R-67 and R-71, Unit B.

	R-67		R-71	
Composite rock fragments	33%	56%	49%	55%
Fragmental quartz	12%		3%	
Fragmental potassium feldspar	10%		3%	
Fragmental plagioclase	1%		<1%	
Biotite	<1%		2%	
Zircon	<1%		not found	
Glass	22%		10%	
Microlites	8%		2%	
Open fractures	not found		2%	
Secondary quartz	8%		2%	
Opal	not found		25%	
Chlorite	4%		1%	
Opaques	1%		1%	
	100%		100%	
Number of points counted	309		187	

or tan.

Two samples of Unit B were examined petrographically. Composition of the rocks, as determined by point counts, is shown in Table 3.

The composition of rock fragments in samples R-67 and R-71 is similar to Unit A. Unit B contains 56 and 55 percent rock fragments, which is slightly more than Unit A.

The rock fragments contained in sample R-67 are nearly the same size as those in Unit A, and the fragments are subrounded to angular. Sample R-71 contains cobbles of granite and of green metamorphic rock, as well as smaller rock fragments. The cobbles are as large as two inches in the longest dimension, and are the largest inclusions observed in Units A, B, or C.

Biotite is present in the matrix of Unit B, but is less common than in Unit A. The biotite grains show little alteration and are not bent.

The matrix of Unit B consists of brown glass and minute mineral fragments. Approximately one-third of the glass of sample R-71 has devitrified. Most of the devitrification products are too small to be identified, and are termed "microlites" in Table 3. About three-fourths of the glass of sample R-67 has devitrified. Many of the products are large enough to be identified as quartz, and are termed "secondary quartz" in Table 3. The matrix does not show any remnants of glass shards.

In thin section, sample R-67 does not show any voids or fractures. Sample R-71, on the other hand, contains some open spaces and many opal-filled spaces that are interpreted to be fractures or joints. The fractures average 0.1 mm in width and are as long as 1.5 mm; many fractures cross rock fragments. The voids in Unit A are about as long as they are wide, and none of the voids were observed to cut rock fragments. The voids of Unit A are interpreted to be primary porosity or (doubtfully) solution cavities.

X-ray diffraction analyses were done on the whole rock and on a light-minerals fraction of sample R-71. Neither analysis showed any clay to be present in the sample. A few weak lines in the X-ray pattern that are not attributable to quartz, orthoclase, or plagioclase may represent a small quantity of hydromagnesite.

Origin of Unit B. Because Unit B has a glassy matrix and contains undeformed, unaltered biotite flakes, the writer has in the past suggested that Unit B might be a lithic tuff. However, later research by W. T. Parry (1975, personal communication) strongly suggests that Unit B is composed of cemented alluvium.

Age. Unit B may crosscut Unit A, because Unit B is exposed at a higher elevation than Unit A. The relationship between Unit B and the Dome Fault is not known.

Unit C

Distribution. Outcrops of Unit C are located along the central and northern parts of the Dome Fault. As can be seen from figure 2, the area of outcrop of Unit C is larger than the areas of either Unit A or Unit B.

Lithology. Unit C consists of rock fragments that are bound together by a siliceous matrix. In several outcrops, the rock fragments are sorted into layers one-quarter inch to one inch thick. Some layers are more visible than others because of differing amounts of hematitic staining.

Outcrops of Unit C are thinly bedded or massive and are predominantly white or tan, but orange or purple streaks of hematite staining are common.

The rock fragments are subrounded to angular and range in size from ten mm to less than 0.5 mm; the average size is about two mm. Petrographic examination shows that the rock fragments are composed of quartz, potassium feldspar, or a combination of those minerals. Plagioclase feldspar and opaque minerals are uncommon components of the rock fragments. Potassium feldspar fragments show both graphic and perthitic intergrowths. Much of the potassium feldspar is very badly altered to kaolinite and sericite. Of the five samples studied, rock fragments make up from 42 to 16 percent of the rock. A few small pumice pebbles were observed in two samples.

The matrix of Unit C is brown glass and microlites. The matrix does not show any shards or other evidence that the original texture was fragmental. Little devitrification of the matrix has occurred.

Voids comprise two to fourteen percent of the samples examined. The voids are irregularly shaped and average 0.2 mm in width. Two samples have alunite, opal, and epidote as rinds within voids. Small grains of a carbonate mineral are present in the matrix and line the voids of one sample; but that sample does not contain opal or alunite.

Chlorite and hematite have formed within the glass matrix in some samples.

Origin of Unit C. Because several outcrops of Unit C show stratification, the evidence is strong that the unit is alluvium that was cemented by silica or carbonate from hot spring waters. The well-stratified portions of the unit may have formed in place. The unstratified portions of the unit may represent open pools of water into which some alluvium was washed.

Age. The stratigraphic relationship between Unit C and Unit A is not known, so the maximum age of Unit C is not known. However, the minimum age of Unit C is Pleistocene because it is offset by the Dome Fault.

Roosevelt Hot Springs Resort Area

The Roosevelt Hot Springs Resort is shown on figure 2. The resort was constructed around 1902 (Salt Lake Mining Review, 1902, July 15, p. 21), and consisted of a hotel, several bathhouses, and a swimming pool.

A channel in the alluvium that is about six feet wide at the head, three feet deep, and twenty feet long is assumed to be the main orifice. Siliceous sinter is exposed in the channel, and the soil in and around the channel is stained by hematite.

A shallow auger hole 100 feet east of the main orifice is about eight inches wide and presently about three feet deep. One foot below the bottom of the auger hole, the soil is 204°F.

Negro Mag Wash Area

Siliceous sinter is found in three places on the north side of Negro Mag Wash, as is shown on figure 2. The sinter is light brown to white in color and is very dense. The westernmost outcrop is about five feet wide and fifteen feet long; its thickness is unknown. This spring may have flowed in historic times, because the foundations of a small building are nearby.

Patches of hot ground near each of the sinter deposits show that hot water is still close to the surface. Several backhoe trenches (shown on figure 2) have been dug into the alluvium and temperatures as high as 130°F were measured a few inches below the bottom of one trench. The smell of hydrogen sulfide is not particularly noticeable around the trenches, but the alluvium in the sides of the trenches is covered with a thin film of sulfur.

Opal Area

Approximately 50,000 square feet of siliceous hot-spring deposits crop out in the southern part of the Roosevelt area, as shown on figure 2. Except for the scarp of the Dome Fault, the maximum relief in this area is ten feet and much of the area is covered by alluvium, so more hot-spring deposits may be present but covered.

A thickness of about twenty feet of the siliceous material is exposed along the fault scarp, but the total thickness of the deposit is not known.

Several pits have been excavated in the hot-spring deposits in section 16. About five feet of attractively banded opal is exposed in these pits, and the rock is much in demand by rockhounds. Section 16 is a state school section, and the opal is presently held on a minerals lease by Mr. A. L. McDonald. The opal has white, red, brown, orange, yellow, and green layers which range in thickness from several inches to less than a quarter of an inch. The colors probably result from staining by algae at the time of deposition. Most of the opal is quite dense, but some layers are porous.

The rest of the siliceous sinter is white to light brown in color, and shows some algal staining. Most layers are impermeable, but some are porous. All of the opal and siliceous sinter is interpreted to have formed on the margins of or within pools of hot water at the ground surface.

Because this material is offset by the Dome Fault, it is probably Pleistocene or older in age.

Drill Holes

In 1968, several holes were driven in and around the opal deposit in section 16 by E. N. Davie. The locations of two of these drill-holes are shown on figure 2; another is in the main opal pit and has been covered.

The top of the easternmost drillhole is four inches in diameter. It reached a depth of 275 feet, where steam blew the drilling equipment out of the hole. Uncontrolled discharge continued for about six weeks until the hole was cemented back. The steam temperature was 270°F, and was observed to increase slightly as discharge continued. Wellhead pressures were not measured, and no analysis of the condensate was made (C. J. von Hoene, 1973, personal communication).

The westernmost drillhole is on the upthrown block of the Dome Fault. It is at least 50 feet deep, and the temperature at that depth is 140°F.

The drillhole in the opal pit is reported to be about 80 feet deep, and the noise of boiling water could be heard in it (A. L. McDonald, 1974, personal communication).

Hematitic Staining of Alluvium

Several patches of red-stained alluvium are found in the central part of the Roosevelt area (see figure 2 for locations). The red staining may have been caused by hot springs or seeps, but the ground in these patches is not presently hot.

Near the westernmost trenches in Negro Mag Wash, a forty-foot-thick zone of hematite-stained alluvium is exposed in the southern wall of the wash.

WATER CHEMISTRY OF ROOSEVELT HOT SPRINGS

The waters of Roosevelt Hot Springs were first described by Lee (1908, p. 20), who said:

P. B. McKean's hot springs, of which there are several, are located on the western slope of the Mineral Mountains, northeast of Milford. The largest of these springs, having a discharge of about 10 gallons per minute, has been improved and a bath house built, to utilize the water for medicinal purposes. The spring is inclosed, so that the temperature of the water as it issues from the rock could not be measured, but as it issues from the pipe leading from the spring it has a temperature of 190°F. Within the spring the water is boiling and steam escapes also from crevices in the rock for a distance of several feet about the spring. The water contains a large amount of mineral in solution *** and is strongly charged with hydrogen sulphide (H_2S). Much of the silica (SiO_2) contained in solution as the boiling water issues from the rocks is deposited as the water cools and does not appear in the analysis. The silica is precipitated as a light-green jelly which changes to white, spongy masses when artificially dried, but which in nature builds about the springs compact stony mounds. On analysis this deposit was found to consist entirely of silica.

The water analysis given by Lee (1908, p. 50) for one of the springs is reproduced in Table 4, along with analyses from 1950 and 1957. The concentrations of sodium and potassium, chloride, and silica reported by Lee are very different from the concentrations reported in the other two analyses. Lee gives the location of the spring that he sampled as section ?, T. 27 S., R. 9 W. (1908, p. 20), and notes that a bathhouse was nearby. It is possible that this spring was not the spring developed for the Roosevelt Hot Springs Resort, which is in section 34, T. 26 S., R. 9 W. Perhaps the spring sampled by Lee was near the small building in Negro Mag Wash (see description on p. 36).

Table 4.--Analyses of water from Roosevelt Hot Springs. Concentrations in parts per million.

	A	B	C
Date of collection	1906	11-4-50	9-11-57
Temperature (°F)	190	185	131
Silica (SiO_2)	101	405	313
Calcium (Ca)	31	19	22
Magnesium (Mg)	9.7	3.3	0
Sodium (Na)	102	2,080	2,500
Potassium (K)		472	488
Bicarbonate (HCO_3)	30	158	156
Sulfate (SO_4)	90	65	73
Chloride (Cl)	87	3,810	4,240
Fluoride (F)	n.d.*	7.1	7.5
Nitrate (NO_3)	1.83	1.9	11
Boron (B)	n.d.*	n.d.*	38
Lithium (Li)	do.	do.	0.27
Iodide (I)	do.	do.	0.3
Residue on evaporation at 180 C	645	do.	n.d.*
Calculated dissolved solids	n.d.*	7,040	7,800
pH	do.	n.d.*	7.9
Location	sec.? T.27S., R.9W.	sec. 34dcb, T.26S., R.9W.	sec. 34dcb, T.26S., R.9W.
Sampled and analyzed by	U.S.G.S.	U.S.G.S.	U.S.G.S.
Source of data	Lee, 1908 p. 50.	Mundorff, 1970, p. 16-17.	Mundorff, 1970, p. 16-17.

*n.d. : not determined

Mundorff apparently assumed that all three analyses were on water from the same spring. He noted (1970, p. 42) that the spring discharge decreased by tenfold from 1908 to 1950, and the dissolved solids content of the water increased by tenfold during the same period.

The springs of the Roosevelt area stopped flowing after about 1963. Two explanations can be proposed for the decline of discharge: (1) the channelways through which the water reached the surface were gradually sealed by deposition of dissolved solids, especially silica, or (2) a general lowering of the water table in the Escalante Valley caused a change in groundwater flow patterns, and one effect was to dry up Roosevelt Hot Springs. The second explanation assumes that

Roosevelt Hot Springs were in close hydraulic connection with the shallow groundwater system, and this has not been proved.

Geochemical Thermometers

Waters of thermal springs and boreholes from many geothermal areas have been analyzed for major elements and trace elements. Comparison of these analyses with the subsurface temperatures encountered in drilling has shown that a relationship exists between subsurface temperature and the concentrations of silica and of sodium, potassium, and calcium in the waters. These empirical "geothermometers" have been used to predict subsurface temperatures when only the water chemistry was known, and in some instances the predicted temperatures have been quite accurate.

In the following sections, the silica and sodium-potassium-calcium geothermometers are applied to Roosevelt Hot Springs.

Silica Geothermometer

Fournier and Rowe (1966) suggested that the silica content of near-boiling hot springs is controlled by the solubility of quartz in the reservoir rocks, and that the temperature at which the water was last in equilibrium with quartz might be estimated from the silica concentration.

Using data for the solubility of quartz between 100^{o} and 375^{o}C, Fournier and Rowe (1966, p. 693-694) calculated the final concentration of silica in waters that have cooled adiabatically to 100^{o}C and decreased in pressure to 1 atm. Their calculations assume that no silica is precipitated from the water prior to sampling, that large quantities of CO_2, H_2S, and other gases did not separate from the fluid as pressures dropped, and that no mixing with cooler or more dilute near-surface waters occurred.

The accuracy of the temperature prediction depends on the accuracy of the silica analysis. If colorimetric methods are used to determine the quantity of silica in a given sample, then the freshness of the sample is of critical importance. White, Brannock, and Murata (1956) state that unless samples are fresh, the amount of silica determined by colorimetric methods is much less than that determined by gravimetric methods.

The analyses of Roosevelt Hot Springs water given in Table 4 give the silica concentration as 101 ppm, 405 ppm, and 313 ppm; but the method of determination and the time lapse between sampling and analysis are not given. However, the concentrations reported can be considered as minimum values. Using the data of Fournier and Rowe (1966, p. 694), the temperature of last equilibration of the hot water with quartz is 210°C for 405 ppm silica, and 195°C for 313 ppm silica. Lee's analysis (1908, p. 50) of 101 ppm silica probably does not represent the true concentration of silica in the water that he sampled.

Sodium-Potassium-Calcium Geothermometer

A relationship also has been observed between subsurface temperatures and the potassium, sodium, and calcium content of geothermal waters. Several workers have suggested that the observed effect is because the partitioning of alkalies between solutions and solid phases is temperature-dependent.

Fournier and Truesdell (1973) proposed that the concentrations of sodium, potassium, and calcium in geothermal waters can be explained entirely in terms of silicate reactions, even though the absolute quantity of aqueous Ca is controlled by the solubility of carbonate.

Following the method of Fournier and Truesdell, (1973, p. 1266-1267), a chemical analysis of a sample of geothermal water can be used to calculate the temperature of last equilibration of the water with Ca-, Na-, and K-bearing silicate minerals. This calculation was made for analyses B and C of Table 4. Analysis B yielded a temperature of equilibration of 298°C, and analysis C yielded a temperature of equilibration of 292°C.

Discussion

The reservoir temperatures estimated by the silica method are 210° and 195°C for analyses B and C. These temperatures are much lower than the 298° and 292°C yielded by the sodium-potassium-calcium method.

The lower temperatures yielded by the silica method may indicate that silica concentrations were decreased by mixing with cool waters near the surface. The sodium-potassium-calcium geothermometer may give a better estimate of subsurface temperature because evaporative concentration of the spring water or mixing with dilute waters would not affect the ratios of the ions, and because analytical error is less likely with these ions than with silica. However, the temperature estimates based on the Na-K-Ca geothermometer may be low. Fournier and Truesdell (1973, p. 1270) state that the Na-K-Ca geothermometer will commonly yield temperatures lower than the reservoir temperature because of continued reaction with wallrocks at lower temperatures during ascent.

For these analyses, temperature estimates yielded by the silica method are less reliable than estimates by the Na-K-Ca method because the method of silica determination is not given and the amount of evaporative concentration of the samples is completely unknown.

It may be significant that the temperature of the spring at the time sample B was collected was higher than when sample C was collected, and that, by both methods, analysis B gives a higher subsurface temperature estimate than analysis C.

POSSIBILITY OF A COMMERCIAL GEOTHERMAL SYSTEM IN THE ROOSEVELT AREA

At the present time, only about ten geothermal systems in the world have been commercially developed (Koenig, 1971, p. 12). The largest installations are: The Geysers in California, with 405 megawatts generating capacity installed; Larderello, Italy, with 365 megawatts; Wairakei, New Zealand, with 160 megawatts; and Cerro Prieto, Mexico, with about 75 megawatts. The Geysers and Larderello fields produce dry steam, and the Wairakei and Cerro Prieto fields produce hot water that flashes to steam.

Although other applications of geothermal resources may someday be important, only one type of large-scale development is now economically feasible: utilizing geothermal steam to generate electricity. Therefore, the basic requirement of a commercial system is that sufficient steam be produced to run a turbine. At The Geysers, 18.53 lb of steam are required to produce one kilowatt-hour of electricity; and future generating plants will be built when an area within the field can demonstrate a steam capability equivalent to 100,000 kilowatt-hours (Garrison, 1972, p. 1450-1451).

The four component parts of a commercial geothermal system are: a heat source, a reservoir, a cap rock, and water. The heat source is presumably hot rock or magma, and is buried beneath the reservoir. Heat is conducted from the hot rock into the reservoir through the intervening rocks.

The reservoir must have sufficient porosity and permeability to yield the required amount of steam to the wells. At Wairakei, the reservoir rocks are a breccia aquifer and faulted fissure zones in a low-porosity ignimbrite (Ellis, 1970, p. 215). Wells drawing on the aquifer storage have permeabilities of one darcy and higher (Garrison, 1972, p. 1456). At The Geysers, the steam reservoirs are primarily shear zones, which are related to faulting (Garrison, 1972, p. 1456).

The reservoir must be isolated from the surface of the earth by relatively impermeable rocks; otherwise large volumes of hot fluids would not be trapped in the reservoir zones. These relatively impermeable rock units are generally called "cap rocks". At The Geysers, Garrison (1972, p. 1456) suggests that the cap rock may be innately impermeable, or that deposition of minerals, such as silica, may have sealed the rocks. At Larderello, highly permeable limestones that form the reservoir are overlain by an impermeable allochthonous series of rocks (Garrison, 1972, p. 1457).

At The Geysers, the water in the reservoir body and the boiled-off vapor are primarily meteoric in origin (Garrison, 1972, p. 1456). The recharge area and the rate of recharge are poorly known.

In the following section, speculations are made on the existence of the four components of a geothermal system in the Roosevelt area. These speculations are based on the geological and geochemical data gathered in this study.

Possibility of a Heat Source

The Mineral Range pluton is relatively young, and the Ranch Canyon volcanics are even younger. These rocks show that igneous activity has occurred at least intermittently during late Tertiary time in the Roosevelt area.

The steam well, hot springs, and the favorable geochemical data yielded by their waters indicate that heat is present in the subsurface.

The data indicate that there is a high probability that a hot subsurface igneous body exists in the Roosevelt area.

Possibility of a Reservoir

Primary porosity in the granite and the metamorphic rocks is probably very low. If Paleozoic sedimentary rocks are present beneath the alluvium, they can be expected to have higher primary porosity.

Secondary porosity along faults may be very important.

Possibility of a Cap Rock

If a cap rock exists in the Roosevelt area, it most probably consists of rocks that have been sealed by the deposition of minerals from the hot water. However, other types of cap rocks might be present. An interesting suggestion, which must be considered completely speculative, is that thrust faults similar to those exposed at the north end of the Mineral Range could be present beneath the alluvium in the Roosevelt area, and might act as a capping unit.

More study is needed to determine if a cap rock does exist in the Roosevelt area.

Possibility of Water

There are not sufficient data to evaluate the hydrologic conditions that might prevail in a geothermal system in the Roosevelt area. Little is known about the shallow (less than 1,000 feet deep) aquifers in the alluvium of the portion of the Escalante Valley that is included in the Roosevelt area; and even less is known about hydrologic conditions in the underlying bedrock.

Wells are necessary to determine the temperature, and quantity and quality of fluids in the subsurface.

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